

Search for new particles at the ILC

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Although the LHC experiments have searched for and excluded many proposed new particles up to masses close to 1 TeV, there are many scenarios that are difficult to address at a hadron collider. This talk will review a number of these scenarios and present the expectations for searches at an electron-positron collider such as the International Linear Collider. The cases discussed include SUSY in strongly or moderately compressed models, mono-photons, indirect BSM via SMEFT fits, and new scalars.

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1. The strong points of ILC for searches

The International Linear Collider (the ILC [1], Fig. 1) will collide polarised electrons with polarised positrons. Energies at the centre of mass will be between 250 GeV and 500 GeV. Possibilities to go to 1 TeV, and operate at $E_{CMS} = M_Z$ are also envisaged. The electroweak production implied by the e^+e^- initial state leads to low background rates. This is advantageous for the detector design and optimisation: The detectors do not need to be radiation hardened, allowing a tracking system to be realised with a total thickness as low as a few percent of a radiation-length. The detector system can have a coverage of nearly 4π , and the low rates means that it does not need to be triggered, so that *all* events produced will be recorded. In addition, the initial state is fully known at an e^+e^- machine, since point-like objects are colliding. This will be quite important for many searches for new phenomena. The ILC has a 20 year running plan defined, with programmes giving integrated luminosities of 2 and 4 ab^{-1} at $E_{CMS} = 250$ and 500 GeV, respectively. It could provide 8 ab^{-1} at the possible upgrade to 1 TeV. The construction of the ILC is currently subject to a high-level political consideration in Japan.

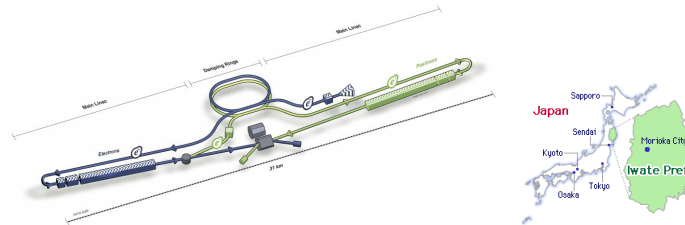


Figure 1: Schematic of the ILC and the location of the proposed site in Japan's Tohoku region.

In order to perform searches or measurements Beyond the Standard Model (BSM) as well as precision measurements of the standard model (SM) requires that the excellent conditions offered by the accelerator are matched by excellent detector capabilities. Specifically, a jet energy resolution of 3-4%, an asymptotic momentum resolution of $\sigma(1/p_{\perp}) = 2 \times 10^{-5} \text{ GeV}^{-1}$, and a measurement of impact-parameters better than $5 \mu\text{m}$ will be required. The detectors should be hermetic, with no other gaps in the acceptance than the unavoidable vacuum tubes bringing the beams into them. In addition, the detectors must be able to record data without being triggered, and to avoid the need for active cooling, they must be able to operate in power-pulsed mode, i.e. with the electronics switched off between bunch-trains. The two detector concepts currently under consideration for the ILC - the International Large Detector concept (the ILD)[2] and the Silicon Detector (SiD) [3] - are equipped with high granularity calorimeters optimised for particle flow that allowing the required resolution of the jet energy. Extensive simulations show that both concepts can meet all requirements.

2. BSM at ILC: SUSY

SUSY [4] is the most complete theory of BSM, and should therefore be given special attention. Naturalness, the hierarchy problem, the nature of dark matter (DM), or the observed value of the magnetic moment of the muon, are all reasons to prefer a light electroweak sector of SUSY.

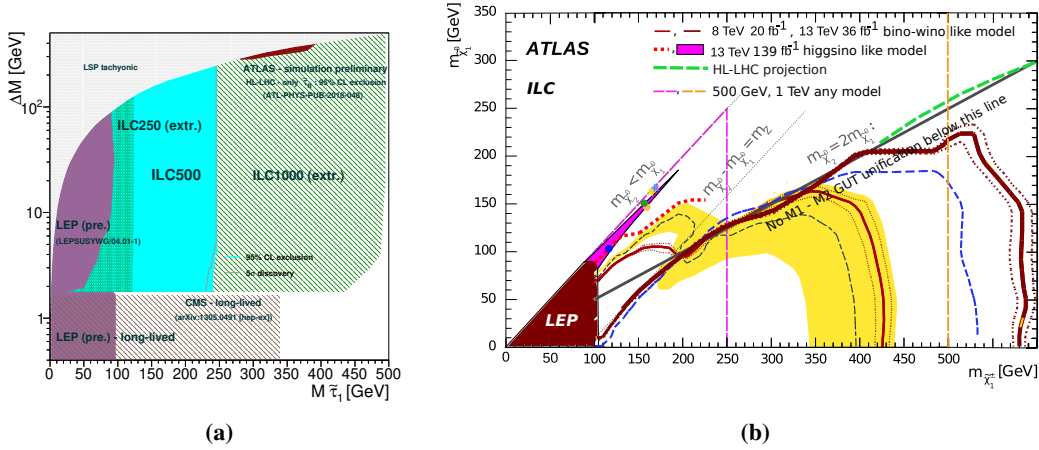


Figure 2: Observed or projected exclusion regions for a $\tilde{\tau}$ (a) or a $\tilde{\chi}_1^\pm$ (b) NLSP, for LEP II, LHC, HL-LHC and for ILC-500 and ILC-1000. For the ILC curves, discovery and exclusion reach are both within the width of the lines.

Moreover, many models and the global set of constraints from observation points to a *compressed spectrum*. If the Lightest SUSY Particle (the LSP) is a Higgsino or a Wino, there must be other bosinos with a mass close to it, since the \tilde{H} and \tilde{W} fields have several components, leading to a close connection between the physical states of the bosinos. Although the third possibility - a Bino-LSP - has no such constraints, an overabundance of DM is expected in this case [5]. To avoid such a situation, a balance between early universe LSP production and decay is needed. One compelling option is $\tilde{\tau}$ co-annihilation, and for this process to contribute sufficiently, the density in the early universe of $\tilde{\tau}$ and $\tilde{\chi}_1^0$ must be close, which means that their masses must be quite similar. In the case of such compressed, low $\Delta(M)$, spectra, most sparticle-decays occur via cascades, with the last decay in the cascade - that one to SM particles and the LSP - has a small $\Delta(M)$. For such decays, the current limits from LHC are for specific models, and only the LEP II limits are model-independent. Indeed, current observations from LHC run 2, LEP, g-2, DM (assumed to be 100% LSP), and precision observables together also suggest a compressed spectrum [6].

At ILC, it is possible to perform a loophole free SUSY search, since in SUSY, the properties of the production and decay of NLSPs are fully predicted for given masses of the LSP and the NLSP. All possible NLSP candidates can therefore be searched for in a systematic way. In Fig. 2 shows the current or projected limits for a $\tilde{\tau}$ NLSP (a) [7], or a $\tilde{\chi}_1^\pm$ one (b) [8, 9]. As can be seen in the figure, exclusion- and discovery-reach is very close at ILC, so that, at the ILC, a SUSY discovery would take place quite quickly. The situation that a interesting SUSY signal is at the intermediate level (neither excluded, nor discovered) for years will never occur: Either the process is not reachable and there is no sign of it, or it will be discovered immediately. This means that SUSY studies at the ILC would almost immediately enter the realm of precision studies. The plots in Fig. 3 shows a number of examples of the type of signals that can be expected: Typical slepton signal ($\tilde{\tau}$, $\tilde{\mu}$ and \tilde{e}) in the top row, in a $\tilde{\tau}$ co-annihilation model (FastSim) [10]. Typical chargino and neutralino signals in different Higgsino LSP models are shown in the following rows. The two plots on the left are

models with moderate (a few to some tens GeV) ΔM (FullSim) [11], while those on the right are for a model with very low (sub-GeV) ΔM (Fast/FullSim) [12]. In all the cases illustrated, SUSY masses could be determined at the sub-percent level, the polarised production cross-sections at a level of a few percent. Many other properties could also be obtained from the same data, such as decay branching fractions, mixing angles, and the spin of the sparticle.

3. BSM at ILC: New scalars, small deviations from the SM, mono-photons

Many BSM models predict the existence of a new Higgs-like scalar (S), produced in $e^+e^- \rightarrow Z^* \rightarrow ZS$ with unknown decays of S . Such a state could have escaped detection at LEP if its production cross-section is much less than that of a SM Higgs of the same mass. Therefore, a search for such a state must be performed at all available masses, and without any assumptions on the decay modes. At ILC, this search can be made using the recoil-mass, i.e. the mass of the recoiling system relative to the measured Z . In [13], a full detector simulation study was performed, and it was found that couplings down to a few percent of the SM-Higgs equivalent can be excluded, see Fig. 4(a).

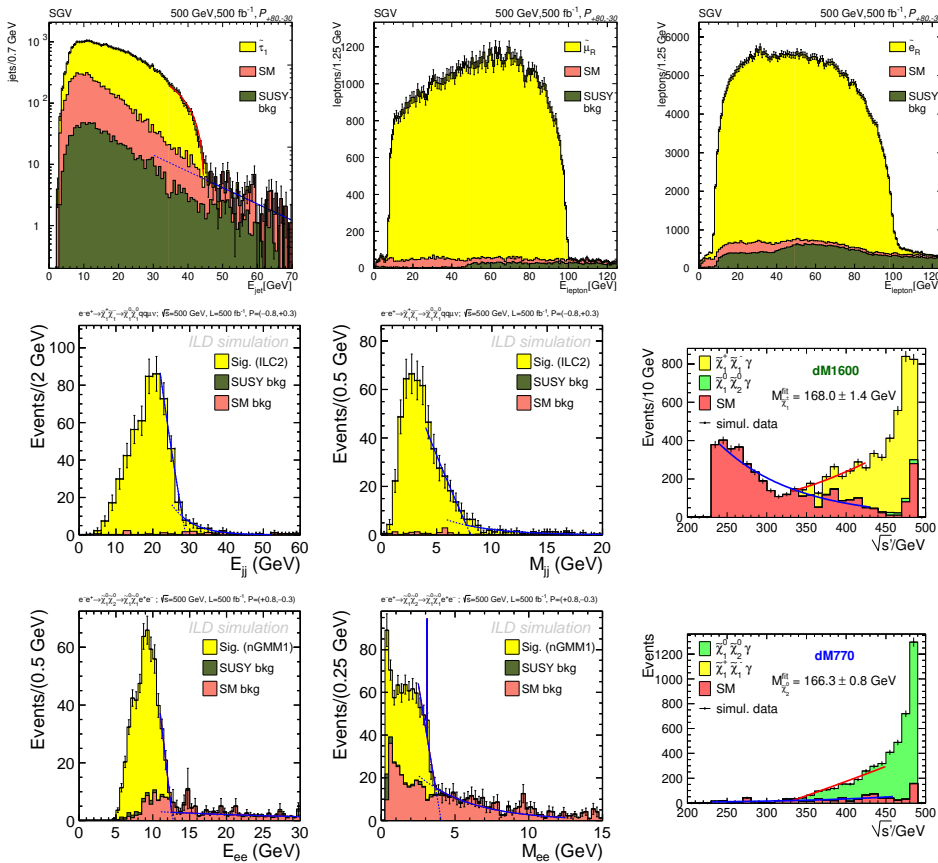


Figure 3: Top row: $\tilde{\tau}$, $\tilde{\mu}$ and \tilde{e} spectra. Middle and bottom rows: Observables for three different Higgsino-LSP models. The middle row shows the case of $\tilde{\chi}_1^\pm$ production, the bottom one that of $\tilde{\chi}_2^0$ production.

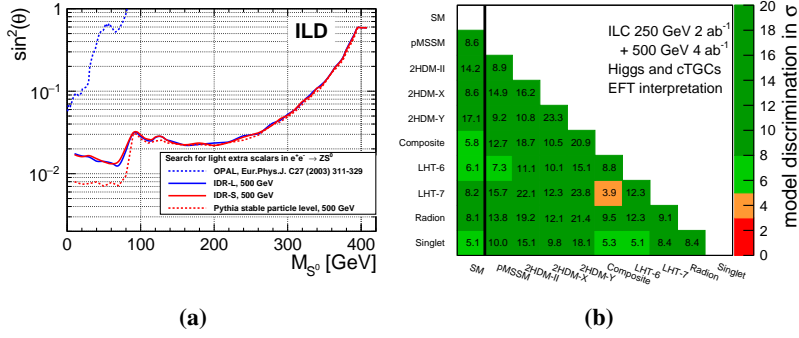


Figure 4: (a) Projected exclusion limit for new scalars, in terms of the coupling compared to the coupling an SM Higgs at the same mass would have. (b) Significances of SMEFT deviations from the expectation, both for the SM expectation and the expectation of each of the various listed models.

The ILC also offers powerful capabilities to detect BSM through indirect searches, i.e. detect deviations from the behaviour predicted by the SM. These deviations can not only be detected, but they can also often be used to separate models. An example of this route to BSM physics is shown in Fig. 4(b) where we show a Standard Model Effective Field Theory (SMEFT) study [14] using ILC results on Higgs properties and triple gauge couplings (TGCs). Here, the authors have selected models that cannot be detected at the HL-LHC. We note that ILC can both separate all the models from the SM (at the 5σ level), but also separate them from each other, at a similar confidence level.

Dark matter can be searched for at ILC in $e^+e^- \rightarrow (DM)(DM) + ISR\gamma$, i.e. in Mono-photon searches. Results of such searches are shown in Fig. 5(a) and (b), both for heavy mediators (a), where a model independent EFT approach is appropriate [15], and for arbitrary mediators (b), where the sensitivity will depend on properties of the mediator [16]. Both cases show potential beyond HL-LHC reach.

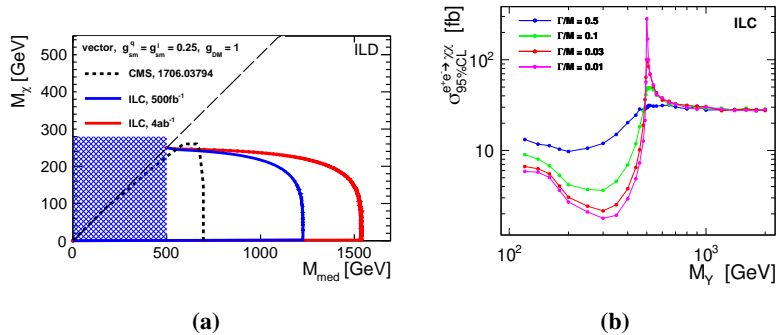


Figure 5: Dark matter searches using the Mono-photon signature at ILC. (a) Heavy mediators, allowing for an EFT approach. (b) Arbitrary mediator masses, for various assumed widths of the mediator.

4. Conclusions

The potential for direct discovery of new particles at ILC could exceed those of the LHC in certain some well-founded scenarios. This is because ILC offers a clean environment without QCD backgrounds, and a well-defined initial state. Furthermore, the ILC detectors will be more precise, will be hermetic, and will not need to be triggered. In addition, ILC can be extended in energy and have polarised beams.

Synergies between ILC and LHC are expected: the LHC experiments will have higher energy-reach, while those at ILC will be more sensitive for subtle signals. For example, if SUSY is reachable at the ILC, precision measurements can be made. This input would help interpret any anomalies seen at the LHC, and might even be what is needed to turn a 3σ excess into a discovery of states beyond the reach of ILC.

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